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DUST-EXPLOSION HAZARDS FROM CERTAIN POWDERED METALS

BY

HYLTON R. BROWN

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

DUST-EXPLOSION HAZARDS FROM CERTAIN POWDERED METALS 1/

By Hylton R. Brown 2/

Many persons who readily recognize the possibility of a dust explosion in a plant handling carbonaceous dust are inclined to accept with mental reservations the statement that metallic dusts also may be explosive. It is difficult for them to understand how metals such as iron, zinc, aluminum, and tin commonly considered noncombustible, can burn with great rapidity and explosive violence when in a finely-divided state.

Explosions have occurred frequently enough in connection with the production and handling of carbonaceous dusts to be generally recognized, and safety codes or standards containing recommendations for protection against such explosions have been prepared for a number of industries where the hazard exists. 3/ It is only recently that metal powders other than aluminum and zinc have been produced in relatively large quantities. This increased production has been brought about by the rapid growth of powder metallurgy - the fabrication of metal machine parts and other objects from finely divided metal powders or mixtures of such powders. More than 30 different types of metal powders are now on the market, and many of them are handled in such large quantities that their production is referred to in thousands of tons. Although the layman may be skeptical about the explosive properties of metal dusts, experienced producers and users have recognized the hazard, and many have endeavored to provide the necessary protection. These efforts to provide safe operating conditions and the necessity of guarding against ignition of such dust should be brought to the attention of new operators and employees as additional plants are opened and other uses for metal powders are developed.

Established operators have submitted some samples of dust to testing laboratories to determine ignition temperatures, explosive limits of concentration, and the various factors that affect explosibility. However, many of the new powdered metals and alloys have not been tested to determine their relative inflammability, and for some of the other metal dusts only data based upon preliminary tests are available. It may be interesting to note that some of the metal powders tested have been classified as more explosive

1/ The Bureau of Mines will welcome reprinting of this paper provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Report of Investigations 3577."

2/ Senior engineer, Safety Division, Bureau of Mines, Pittsburgh, Pa.

3/ National Fire Codes for the Prevention of Dust Explosions, obtainable from National Fire Protection Association, contains codes adopted by the N.F.P.A. and approved by the American Standards Association.

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than the coal and other carbonaceous dusts that have been responsible for many serious explosions in the past. Present experience indicates that essentially the same factors that affect the inflammability of carbonaceous dusts must be considered in determining the explosive properties of metal powders.

DUST IGNITION AND FLAME PROPAGATION

The ease with which a dust cloud can be ignited and the rate at which flame will propagate through the cloud from the point of ignition depend largely on the size of the dust particles as well as on the density of the cloud and other conditions. Physicists have pointed out that in general (1) the finer the dust the more inflammable it is, (2) the finer the dust the smaller the flame or spark required to ignite it, and (3) the finer the dust the longer it remains in suspension in air, where it can be ignited most readily. There are many other factors, however, that must be considered in any study to determine the relative inflammability of a dust or the seriousness of a dust-explosion hazard in an industrial process. In testing carbonaceous materials the percentage of ash and the amount of volatile matter may indicate the relative inflammability of the dust sample. Other factors that must be considered in virtually all dust-explosion tests are the shape of the dust particle and the moisture content; the ease with which the dust can be dispersed to form a cloud; the uniformity of size of particles forming the cloud; the density of the dust cloud; the uniformity of distribution or spacing of the particles; the presence of an ample supply of air or oxygen to support combustion; the size or nature of the ignition source; and the ease of oxidation of the dust particles.

The rate at which any substance will oxidize or burn depends on the surface exposed to the oxygen of the air, and when any solid substance disintegrates into dust its surface area is increased enormously. This increase in surface area can be illustrated by dividing a cube into smaller cubes. A 1-inch cube presents 6 square inches of surface, but if this solid block is divided into smaller cubes, each side measuring 1/100 inch, there will be 1,000,000 cubes with a total exposed surface of 600 square inches. A further reduction to 1/1,000-inch cubes would increase the surface to 6,000 square inches. One investigator has estimated that 1 pound of some of the finest metal powders has an expanded surface of about 220,000 square inches.

Experiments show that the ignition temperature of some dusts drops rapidly as the size of the particle is reduced. In reporting the temperature of ignition of various dusts, Price and Brown[4] showed that a sample of cork dust, about 90 percent of which would pass through a 200-mesh screen, ignited at 1,080° C., while a sample that completely passed the 200-mesh screen could be ignited at 975° C. Similarly, a sample of starch with 80 percent passing a 200-mesh screen ignited at 1,035° C., while the sample that completely passed the screen could be ignited at 960° C. The ignition temperature of 150-mesh coal dust is 50° C. lower than that required to ignite 48-mesh samples. Although Beyersdorfer does not give the particle size, he reports[5]

4/ Price, D. J., and Brown, H. R., Dust Explosions: National Fire Protection Association, Boston, Mass., 1922, pp. 14-15, table I.

5/ Beyersdorfer Über den Begriff Feurgefährlichkeit: Zeitschr. tech. Physik, vol. 9, No. 1, 1928, pp. 17-19.

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485° C. as the ignition temperature of aluminum powder and 230° C. as the temperature at which fine aluminum grindings can be ignited. Additional research on this subject with metal dust is being planned.

In still air, the rate at which dust particles will settle is directly proportional to the density of the particles and the square of their radius. In industrial plants air currents may tend to keep small particles in suspension indefinitely and thus build up an explosive dust-and-air mixture, which presents a constant hazard. Experiments have shown that flame is propagated most readily in dust clouds in which the particles are small, of uniform size, and uniformly distributed. Under such conditions flame velocities of 2,000 to 3,300 feet a second have been measured, with indications of much higher velocities, probably greater than 6,000 feet per second.

METAL-POWDER PRODUCTION

There are a number of different methods of producing metal powders, and the various processes are being improved from time to time. There are also variations in the several processes to allow the manufacture of different types of powder particularly suitable for special purposes. A list of the more important processes includes atomization, chemical precipitation, condensation, electrolytic deposition, machining, milling, and reduction. Except where the powder is produced or handled in dry form, there is no dust-explosion hazard in connection with the manufacturing operation.

In the atomizing process the molten metal is forced through an orifice or nozzle, where it is struck by a jet of steam or compressed air or gas; and, as the metal solidifies in the form of fine powder, it is carried along with the air or gas stream to the collecting equipment. Explosive concentrations generally are present both in the ducts that carry the air and dust stream and in the dust collector.

Both dust- and gas-explosion hazards are present in the condensation process, which is used principally in the production of zinc and lead powders. The vaporized metal is reduced in an atmosphere of carbon monoxide and passed through a condenser. The rate of cooling determines the size and type of powder produced.

Machining is the process generally employed to produce magnesium powder because of the difficulty experienced in preventing dust ignitions or explosions in other processes. Machining may be described as a large-scale or mechanized filing or cutting process, and the explosion hazard exists wherever quantities of the dust or powder produced are in suspension in air during preparation or handling.

Probably the most widely used method of producing metal powders is the milling process. The generally accepted term includes the production of powder in stamps, crushers, rolls, ball, bar, and disk mills, attrition mills, eddy mills, and jet pulverizers. In the last two types of equipment, air currents are employed in the grinding operation, and in all of the other types there is enough air movement to create dust clouds within or around the milling equipment during normal operation.

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Two methods of milling designed to reduce the explosion hazard have been developed. One method, known as the Hall process, provides for the mixing of a liquid with the material entering the mill to form a slurry or paste and thus eliminate dust ignitions within the mill. The explosion hazard is still present to some extent if it is necessary to dry or further condition the product after milling. The other method, known as the Hametag process, employs a stream of inert gas to carry the powder away from the mill as it is produced. The purpose is to prevent both oxidation and explosions. Fairly effective protection against explosions can be obtained in certain instances where an inert gas can be found that is effective in preventing ignition of the powders being produced and can be used to carry the material to the collectors or separators.

Metal powders are produced in a wide range of sizes, and different processes produce particles of different shapes. Certain types and sizes are better suited than others for particular uses. For instance, a flaked powder is desired for making aluminum paint, while angular particles are better for some forms of powder metallurgy. Very fine particles are necessary for making inks used for fine surface printing, decorating, or lining; and here, again, flaked powders produce better leafing or coverage. Although very coarsely divided metal in the form of shot sometimes is referred to as powder, it seems desirable, at least in discussing explosion hazards, to include only the commonly marketed sizes that may be ignited as a dust cloud. Under such classification the particle size of dusts considered explosive would extend from the 30-mesh magnesium used in pyrotechnics to the 400-mesh and finer bronzing powders used in high-grade printing inks. Some of these finer powders are reported to be about 0.4 micron thick.

In connection with metal-powder production, screening and packaging operations constitute dust-ignition hazards similar to those in other dusty industries employing the same type of equipment. Screens, bolters, sifters, reels, dust collectors, and similar machinery are required to make the necessary size separations, and generally some dust clouds are formed in or around packaging machinery.

POWDER METALLURGY

The present stage of development of the fabrication process in which the metal powders, either singly or mixed, are pressed to the desired shape apparently presents a limited explosion or dust-ignition hazard. Hydraulic, toggle, cam, and other types of presses may be employed, provided they can produce the necessary pressure. The pressure used ranges from a few tons to more than 100 tons per square inch. The die parts are of hardened tool steel. The swagings now being produced are generally small, and the powder required for the individual pressings may weigh only a few ounces. However, pieces weighing 40 pounds or more have been produced, and large quantities of powder may be stored in the hoppers or bins of the automatic presses, from which it is fed in the desired amount to the die or mold. The ignition hazard is present while a bin or hopper is being filled with the powder or when failure of the feeding mechanism or spills create a dust cloud around the press.

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Following the pressing operation the parts are sintered or heat-treated for a short time. Because the material is no longer in powdered form, there is no dust-explosion hazard in this operation. Some attention has been given to the possibility of eliminating this step in the process by hot pressing. Additional sources of ignition may be introduced in providing for hot pressing, and exceptional care will be necessary to prevent the metal powders that ignite at relatively low temperatures from coming in contact with highly heated parts of the press while they are in the form of a cloud.

INFLAMMABILITY OF METAL POWDERS

Aluminum powder has been produced in large quantities for many years. Increased use of aluminum paint stimulated production of the powder, and a number of serious explosions in connection with the production of the powder directed attention to the hazard of dust ignitions. Extensive laboratory tests have been made to determine the ignition temperature, limits of concentration, and other factors that would indicate the extent of the hazard and aid in the development of protective measures. Ignition has been reported at temperatures as low as 230° C., and references have been made by investigators to ignitions of dust clouds by glowers, induction-coil sparks, electric arcs, and mechanically produced heat. It is known that sparks from a piece of steel in contact with a grinding wheel can ignite a cloud of aluminum powder.

Research to determine the inflammable and explosive properties of other metal powders has been quite limited, and there is a paucity of data on the subject in published material. A number of tests have been made in Bureau of Mines laboratories at the request of producers or users of certain types of metal powders to determine their relative inflammability. These tests are designed to indicate whether the material is more or less explosive than coal dust, comparison being based upon the amount of inert dust that must be added to suppress ignition. The dusts so tested include several types of iron powder, several types of magnesium powder, zinc powder, and tin powder. All of these dusts were found to be explosive. Ignitions were obtained by blowing samples of dust into a furnace operated at temperatures ranging from 425° C. to 660° C. and by using an induction-coil spark as the source of ignition in a tube through which the dust was blown. The amount of inert material it was necessary to add to some of the samples to suppress ignition ran as high as 97.5 percent. With the sample of Pittsburgh-coal dust used as a standard or check, the addition of 65 percent inert material was necessary to suppress ignition. Additional tests are now under way, and an effort is being made to obtain data on the lower limit of concentration at which ignitions can occur. Further research will be necessary to determine the possibility of initiating ignitions by discharges of static electricity and to determine the hazard due to accumulation of electrical charges on the dust particles. As Gibbs points out in his reference to the work of Rudge frequently mentioned in his book, 6/ nearly all dusts become electrically charged when they are blown about in the air; and, as the charge resides upon the surface, the capacity of the dust is proportional to the total surface area. As previously pointed out, the

6/ Gibbs, W. E., The Dust Hazard in Industry: London, 1925, 168 pp.

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finer the dust the greater the surface area and therefore the greater the charge. In the table developed by Rudge after testing nearly 200 different dust samples, the character of the charge detected on different dusts is indicated, and it is interesting to note that the charge found on aluminum, iron, magnesium, tin, and zinc was negative in each instance. In his report on these tests[7] it is pointed out that although many exceptions were noted it seemed to be fairly well established that (1) nonmetallic elements give positively charged clouds when the dust is blown into suspension and (2) metallic elements give negatively charged clouds when finely divided material is blown into suspension in air. Further research to determine the possible effect of the electrical charge present on dust particles in determining their explosibility would seem to be warranted.

PROTECTION AGAINST EXPLOSIONS

At this time it is difficult to make specific recommendations for providing protection against ignitions of metal powders because, as previously pointed out, very little information is available on the factors that affect the explosibility of such materials. It can be assumed, however, that in general the safety codes developed for protection against dust explosions in other industries will be applicable in plants handling the metal powders used in powder metallurgy. Where it is not possible to provide absolute protection against dust ignitions owing to lack of knowledge concerning the inflammability of the product or because of necessary manufacturing conditions, some degree of protection can be provided that will greatly minimize the results of such ignitions and reduce the hazard to life and property. Reference has been made previously to the safety codes for preventing dust explosions developed by the N.F.P.A. Committee on Dust-Explosion Hazards, and particular attention is called to the code for the prevention of dust explosions in the manufacture of aluminum bronze powder and the fundamental principles for the prevention of dust explosions in industrial plants. These two codes and the article on the release of explosion pressure through properly proportioned and properly located vents[8] contain a number of recommendations for providing protection against dust explosions; the principal ones may be summarized as follows:

1. Segregate hazardous processes in small, detached buildings or separate units with fire walls and fire doors.

2. Provide vents, such as light roofs or large hinged window areas designed in the proper proportion, to release explosion pressure without structural damage.

3. Maintain equipment as nearly dust-tight as possible and provide for frequent cleaning to prevent accumulation of dust at points where it may be thrown into suspension to form a cloud.

7/ Rudge, W. A. Douglas, On the Electrification Associated with Dust Clouds: Phil. Mag., ser. 6, vol. 25, April 1913, pp. 481-494.

8/ Brown, Hylton R., and Hanson, Richard L., Venting Dust Explosions: Nat. Fire Protec. Assoc. Quarterly, vol. 26, April 1933, pp. 328-341.

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4. Eliminate all possible sources of ignition by using:

(a) Electrical equipment approved for such locations.
(b) Indirect heating to prevent dust collecting on heated surfaces.
(c) Ground connections on all equipment to remove static electricity.

5. Use inert gas to prevent dust ignitions wherever feasible.

6. Use conveying, collecting, processing, and cleaning equipment designed to perform its function with no possibility of producing metallic sparks or frictional heat capable of igniting the powder being handled.

7. Provide fire-fighting facilities of the type found best adapted to the particular needs of the plant.

NOTE: Water and ordinary types of fire extinguishers are not effective on metal-powder fires and in many instances their use will intensify the fire. They should be rigidly excluded from sections of the plant where their use by inexperienced persons would be dangerous. Disturbance of quietly burning powder by hose streams or other means may cause a serious explosion. Dry sand, talc, rock dust, and similar material have been used to smother small fires in metal powder, but fine graphite is much more effective and is now generally recommended. A special fire-extinguishing powder has been developed for use on magnesium fires. All such inert substances must be applied carefully to avoid any disturbance of the burning material likely to throw it into the air, and the use of this method should be attenpted only by persons familiar with the hazard. No satisfactory method of extinguishing metal-powder fires too large to be covered with powder is now known, and experienced operators usually prefer to seal a fire in the unit in which it started and permit it to burn itself out.

CONCLUSION

Powder metallurgy is an industry in which at present the art is ahead of the science but, as developments continue, additional data on the properties of the different powders no doubt will be available. Our present knowledge of the factors affecting the explosibility of the dusts is likewise limited, but the simple fact that the dusts are explosive, as shown in preliminary tests, should be justification enough for the adoption of all known precautions to prevent ignitions wherever such dusts or powders are produced, processed, or handled. Producers and users of metal powders are urged to cooperate in making available to the industry experiences or data that will contribute to the development of safe practices for explosion and fire protection and thus eliminate or reduce this hazard to life and property.

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